AIRBORNE LIDAR SURVEYS AND REGIONAL SEDIMENT MANAGEMENT

Jennifer McClung Wozencraft[1] and Jennifer L. Irish[2]

1. U.S. Army Corps of Engineers, Mobile District, Joint Airborne Lidar Bathymetry Technical Center of Expertise, OP-J, 109 St. Joseph Street, Mobile, AL 36602 USA, Tel.: 334-690-3466, Fax: 334-690-3464, Email: jennifer.m.wozencraft@usace.army.mil
2. U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Joint Airborne Lidar Bathymetry Technical Center of Expertise, Mobile, AL USA

ABSTRACT

Airborne lidar is an ideal tool for surveying regional scale projects. It is the only tool that can economically provide synoptic bathymetric and topographic data on a regional scale, which is the type of data required for nearshore coastal studies like the Regional Sediment Management Demonstration Program (RSMDP) of the US Army Corps of Engineers Mobile District. The goal of this program is to link changes in nearshore terrain with hydrodynamic forcing. The SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system has been used to collect regional data for the demonstration program. SHOALS data gives a three-dimensional quantification of a region at a particular point in time. Comparison of SHOALS data sets quantifies changes that have occurred between surveys. This paper gives an overview of SHOALS, the RSMDP and the SHOALS data sets that have been collected for the region. An example of how SHOALS is used throughout the region is given by detailing SHOALS data analysis at East Pass, Florida, USA.

INTRODUCTION

Sediment management is a program of engineering practices designed to optimize the operation and maintenance of navigation and shore protection projects. For example, sand is removed from tidal inlets and harbors to ensure navigable waters. The removal of this sand affects the adjacent beaches by interrupting the littoral drift that occurs around natural inlets. Hard structures that also improve navigation have a similar effect, trapping sand updrift and starving shorelines downdrift. A sediment management plan may call for dredged sand to be placed on the adjacent beaches, or for trapped sand to be moved from the updrift side of a project to the downdrift side. In the past, the US Army Corps of Engineers has managed navigation projects and beach restoration projects as separate entities. However, managing sand on a project-by-project basis has often resulted in adverse impacts to adjacent projects and shorelines. For example, sand removed from navigation projects and placed in deep water will never return to the littoral system. Consequently, natural sand supply to downdrift beaches is depleted.

The US Army Engineer District (USAED) Mobile, Alabama, USA, has recently initiated a Regional Sediment Management Demonstration Program (RSMDP) to show that sand can and should be managed on a regional basis. This means that all projects within a designated region are considered as a single system. The RSMDP encompasses 360 km of Gulf of Mexico shoreline stretching from the west end of Dauphin Island, Alabama, USA, east to Apalachicola Bay, Florida, USA (Figure 1). The demonstration region encompasses nine federal navigation projects and one federal beach nourishment project. Reliable and effective sand management and engineering requires terrain models that fully represent the study region. In complex coastal areas, high-resolution bathymetric and topographic coverage is essential for reliable calculation of sand volumes (1).

Recent advancements in lidar technology now allow for near-synoptic, regional scale mapping of the coastal zone. The US Army Corps of Engineers SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system simultaneously collects bathymetry and adjacent shoreline topography using a blue-green laser. SHOALS collects individual soundings every eight meters and surveys at a rate of 400 soundings per second, or 25 km^2 per hour. The accuracy of the soundings conforms to IHO Standards, or ±3 m in the horizontal and ±15 cm in the vertical (2, 3, 4). Many sets of SHOALS data have been collected in the RSMDP since 1995. The data sets were collected as part of inlet monitoring programs, shoreline monitoring programs, emergency hurricane response efforts, and specifically to provide baseline data for the RSMDP. SHOALS data exists for Perdido Pass in Alabama, Pensacola Pass and East Pass

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in Florida, and for the Gulf of Mexico shoreline from west of Perdido Pass in Alabama to east of Apalachicola Bay in Florida. The regional baseline terrain model generated from SHOALS data is presented in Figure 2. The dataset covers 300 km^2 and represents 5 million individual depth and elevation measurements. The intent of this paper is to provide an overview of the SHOALS system and to demonstrate how SHOALS data will be used in the RSMDP, using East Pass, Florida, as an example. The four SHOALS surveys collected at East Pass are presented and compared to quantify this coastal system's evolution.

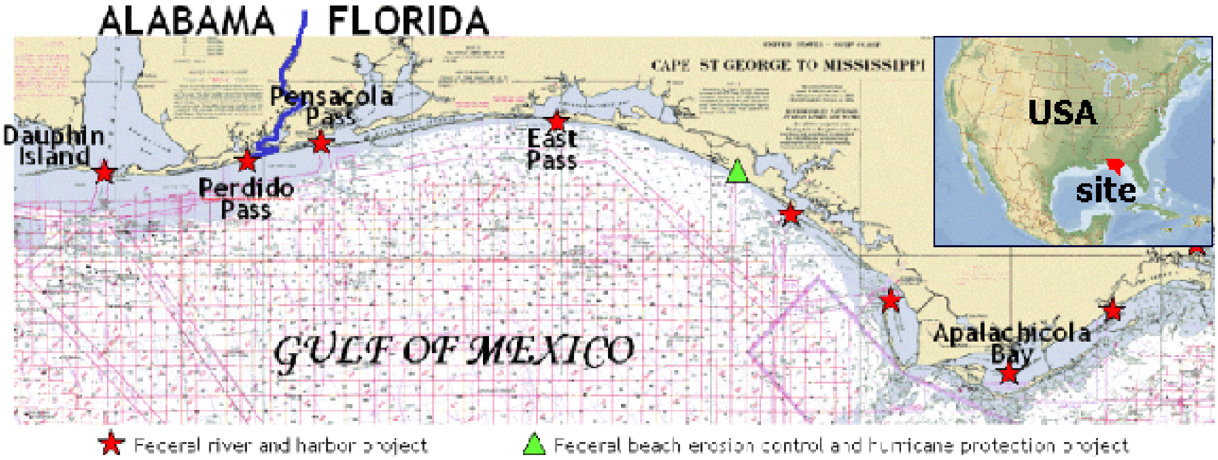

Figure 1. RSMDP area. North is to the top.

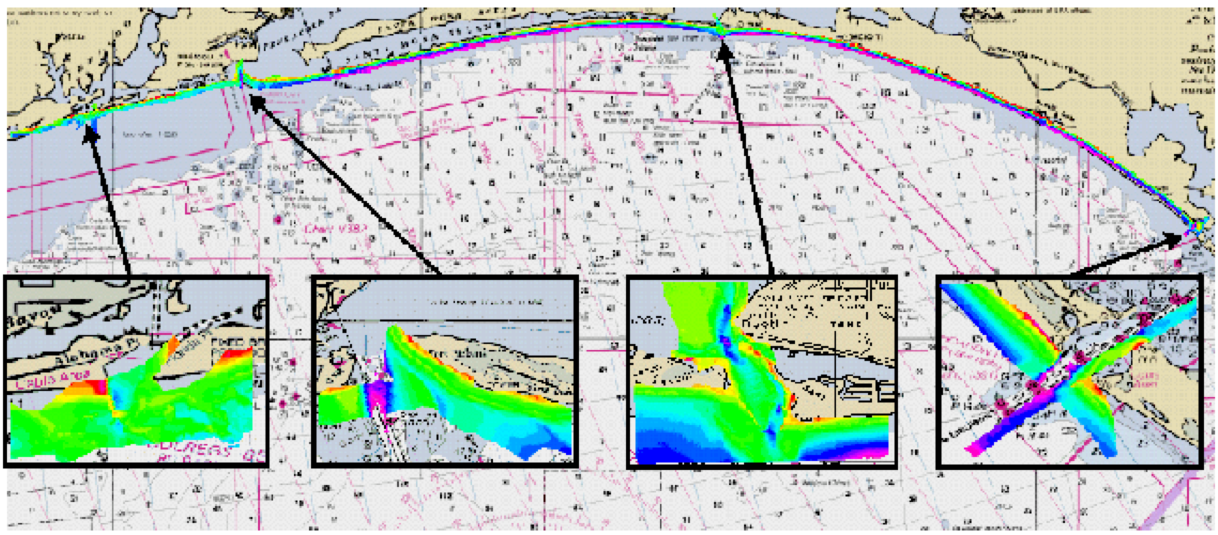

Figure 2. RSMDP terrain model generated with SHOALS data.

THE SHOALS SYSTEM

An ALB sensor uses lidar technology to directly measure water depths (5). A laser transmitter/receiver (transceiver) mounted on an aircraft transmits a laser pulse that travels to the air-water interface where a portion of this energy reflects back to the transceiver (surface return, Figure 3). The remaining energy propagates through the water column and reflects off the sea bottom (bottom return). The water depth comes directly from the time lapse between the surface return and the bottom return. In addition, each sounding is appropriately corrected for water level fluctuations using either vertical aircraft positioning from GPS or by referencing the lidar measurements to water surface location with water level gage measurements.

In practical application of this technology, laser energy is lost due to refraction, scattering, and absorption at the water surface, sea bottom, and as the pulse travels through the water column (Figure 4). The combination of these

effects limits the strength of the bottom return and therefore limits the maximum detectable depth. Optical water clarity is the most limiting factor for ALB depth detection. Typically, an ALB sensor collects through depths equal to three times the Secchi (visible) depth. In optically clear water, ALB sensors have successfully measured to depths to 60 m.

The SHOALS ALB system operates from both fixed-wing and rotary-wing platforms (Figure 5a, 2, 4, 5). Inside the aircraft are the laser transceiver, operator interface consoles, and pilot guidance system (Figure 5). The SHOALS system's laser transceiver emits two energy frequencies: a blue-green frequency (532 nm) and an infrared frequency (1064). In addition, the transceiver records laser energy return time series (waveforms) with four receivers. One receiver records the infrared energy reflected from the water surface (surface return) and two collect the blue-green energy reflected from the sea bottom (bottom return, Figure 3). A fourth receiver records Raman energy, at 645 nm, which results from excitation of water molecules at the sea surface by the blue-green laser energy. The Raman waveform and the infrared waveform indicate distance to the sea surface, while the two blue-green waveforms indicate distance to the sea bottom from 0 m to 10 m and from 10 m to 60 m. The infrared waveform is also used to distinguish dry land from water. Additionally, one blue-green waveform is used to directly range topographic elevations.

The SHOALS laser pulses at a rate of 400 Hz, providing 400 individual range

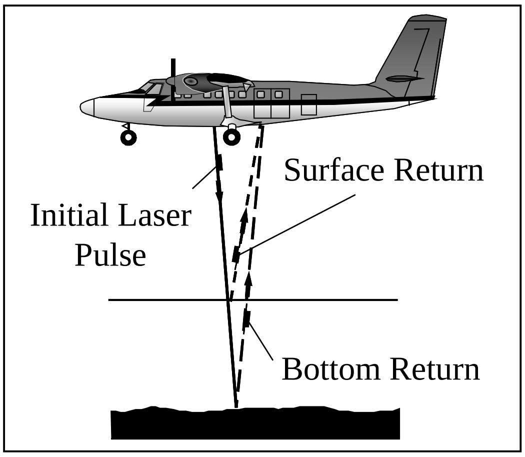

Figure 3. ALB operating principle.

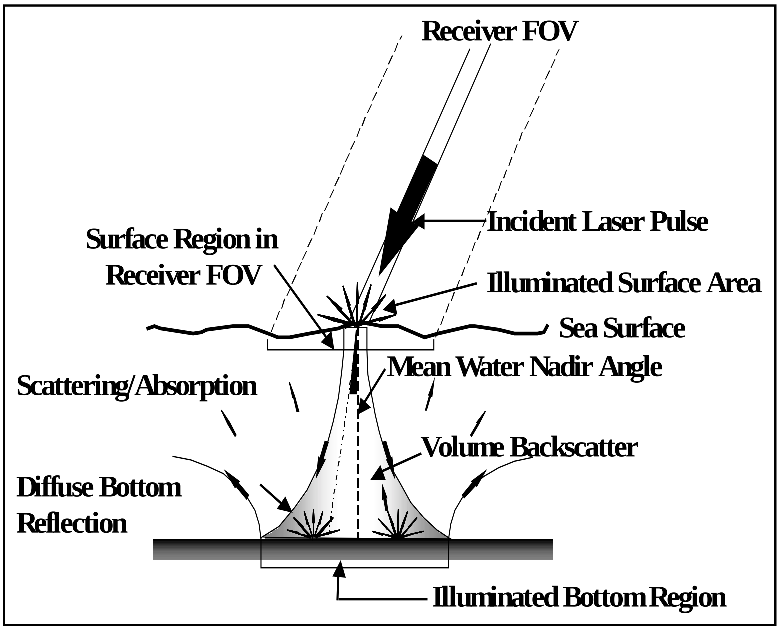

Figure 4. Water column and interface effects on system performance (FOV is field of view).

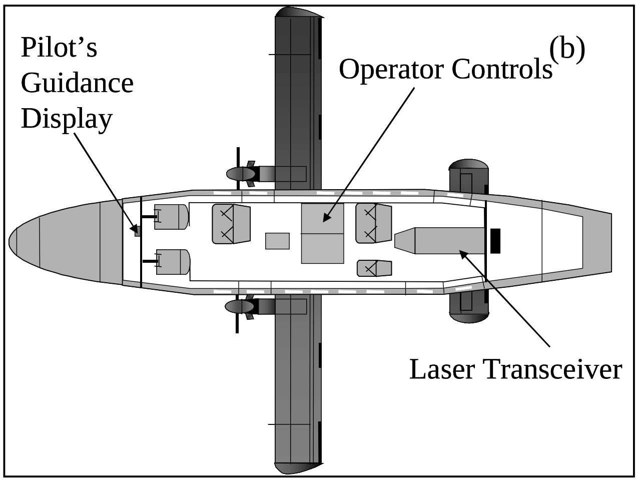

Figure 5. (a) SHOALS system mounted on a Twin Otter and (b) layout of SHOALS system inside Twin Otter.

measurements per second. An optical scanner mounted with the transceiver positions each laser pulse to provide uniform sounding and elevation spacing on the earth's surface (Figure 6). For coastal monitoring surveys, SHOALS typically collects data from an altitude of 400 m, resulting in a scanner swath width of 220 m. Along with an aircraft speed of 60 m/s, this results in an individual sounding or elevation measurement every 8 m and a survey speed of 25 km^2 per hour. Table 1 gives SHOALS operation and performance characteristics.

SHOALS receives its positioning from GPS (Global Positioning System) in either differential (DGPS) or kinematic (KGPS) mode. With DGPS, horizontal positioning of the aircraft is accurately known and directly translates to a known horizontal sounding/elevation position. Accurate vertical positioning for each measurement is then obtained by correlating the lidar surface return with independent water level measurements. In contrast, KGPS provides both horizontal and vertical aircraft positioning accurately, thus the full three-dimensional positioning for each measurement is independent of supporting water level measurements. SHOALS vertical positioning accuracy is ±15 cm and horizontal positioning accuracy is ±3 m and ±1 m with DGPS and KGPS, respectively (4, 6, 7).

The SHOALS system also collects a directly downward-looking, geo-referenced video concurrently with the lidar measurements. In addition to offering a visual record of the survey area, the video is frequently used to position coastal features such as navigation aids, piers, and other objects of interest.

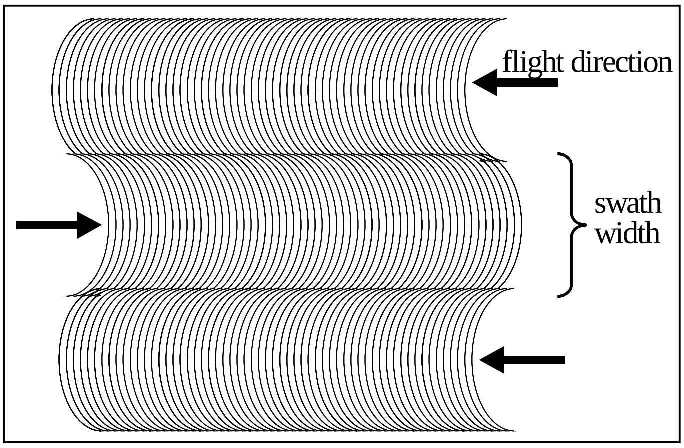

Figure 6. SHOALS scan and flight patterns.

Table 1. SHOALS operation and performance characteristics.

Maximum Depth	to 60 m
Vertical accuracy	±15 cm
Horizontal accuracy	
DGPS	±3 m
KGPS	±1 m
Sounding density	8-m grid (variable)
Operating altitude	400 m (variable)
Scan swath width	220 m (variable)
Operating speed	50 to 70 m/s

SHOALS SURVEYS AT EAST PASS, FLORIDA

East Pass is a tidal inlet located on the Florida panhandle (8). It connects Choctawhatchee Bay with the Gulf of Mexico. Figure 7 is an aerial photo taken at East Pass in 1989. The rubble mound jetties were built in a converging design as part of a Federal navigation project. A navigable depth of 4.3 m is maintained within the Federal channel alignment by periodic dredging activity. Norriego Point is a sand spit that has grown across the channel connecting the inlet interior with Old Pass Lagoon. Old Pass Lagoon marks an historical location for access to Choctawhatchee Bay, when the inlet mouth was located several miles to the east. Other dominant features at the pass include extensive, sandy ebb and flood shoals.

Figure 7. East Pass, Florida, U.S.A. Aerial photo taken in 1989. North is to the top.

Four SHOALS data sets have been collected at East Pass. The first two were part of USAED Mobile emergency response efforts

following Hurricane Opal in October and November of 1995 (9). Most damaging to this inlet system was the significant surge associated with the hurricane. The storm surge caused significant sediment infilling throughout the entire inlet system and caused smaller areas of localized scouring. Figure 8 shows the National Oceanic and Atmospheric Administration (NOAA) nautical chart in the vicinity of East Pass. The overlay is a 3-m contour plot of SHOALS data collected in October 1995. The southern extent of the data is semi-circular in shape, and describes the seaward edge of the ebb shoal labeled in the aerial photo of Figure 7. The three blue areas in the lower central portion of the contour plot are areas of scour at the jetty tips. The scour has an eastward orientation that indicates an asymmetry of ebb-tidal flow out of the inlet. The jetty structures themselves are yellow-orange. The blue area in the upper central part of the contour plot is the navigation channel. The yellow-red area east of the navigation channel is Norriego Point, which breached during the hurricane. The area of lower elevation in the center of the point indicates this breach. The light-blue area just southwest of Norriego Point marks a second channel that extends to the spur jetty.

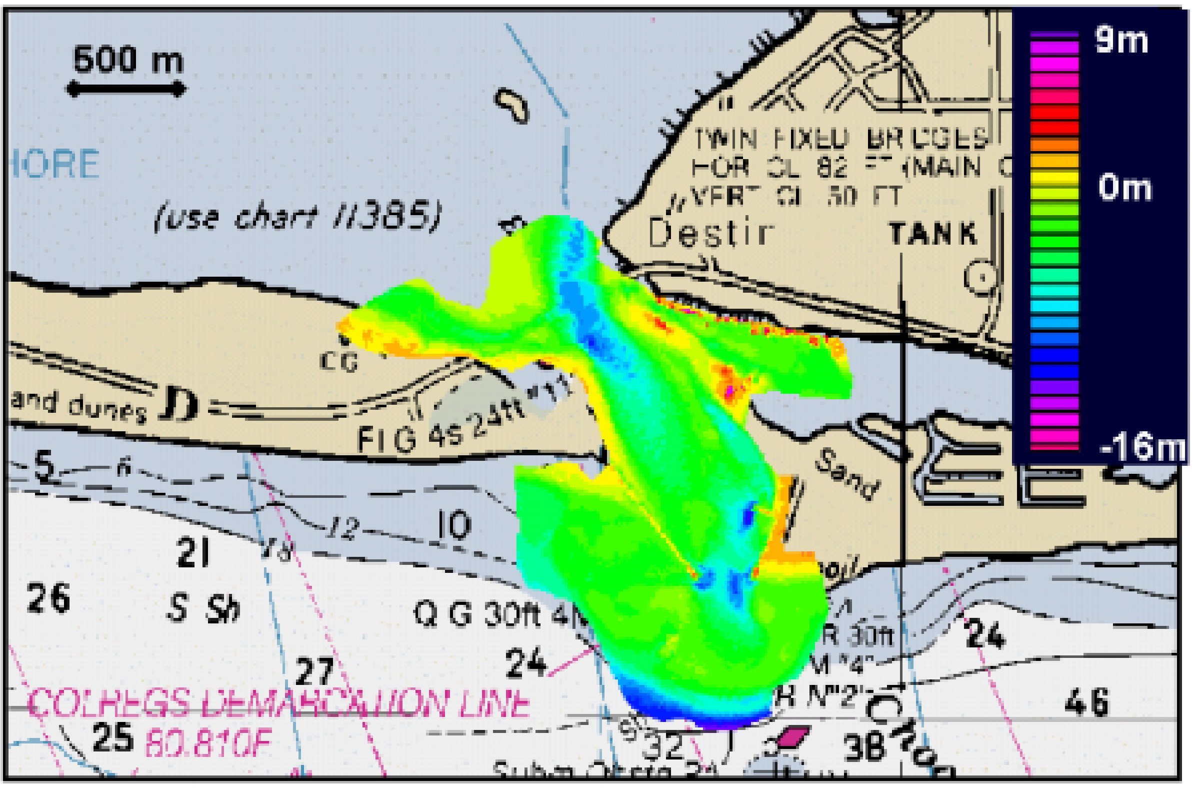

Figure 8. East Pass, Florida, U.S.A. NOAA nautical chart with contours of SHOALS data, October 1995.

A general project condition survey was conducted in December 1996 for USAED Mobile. A contour plot overlay and nautical chart for this data set is shown in Figure 9. With respect to the 1995 SHOALS surveys, this survey extends farther north into the backbay, farther east and west along the adjacent beaches, and farther seaward. This survey provides comprehensive spatial coverage of the ebb shoal, which can be defined by the bright green, arc-shaped area directly south of the inlet. Since 1995, the scour holes at the ends of all three structures have expanded in width as well as in depth. Natural scouring has also occurred in the northern part of the navigation channel, as well as in the deep, natural channel adjacent to Norriego Point. Following Hurricane Opal, sand was dredged from the navigation channel in the inlet throat center and along the outer ebb shoal. This dredged material was used to repair the breach at Norriego Point and to nourish the adjacent beaches. The SHOALS data shows that these areas have increased elevation.

A second project condition survey was performed at East Pass in November 1997 to document post-jetty repair (10). The contour overlay and nautical chart for this data set is shown in Figure 10. The jetties were restored earlier in the year. The areas of higher elevation (shown in red) along the structures are areas where additional rock was placed

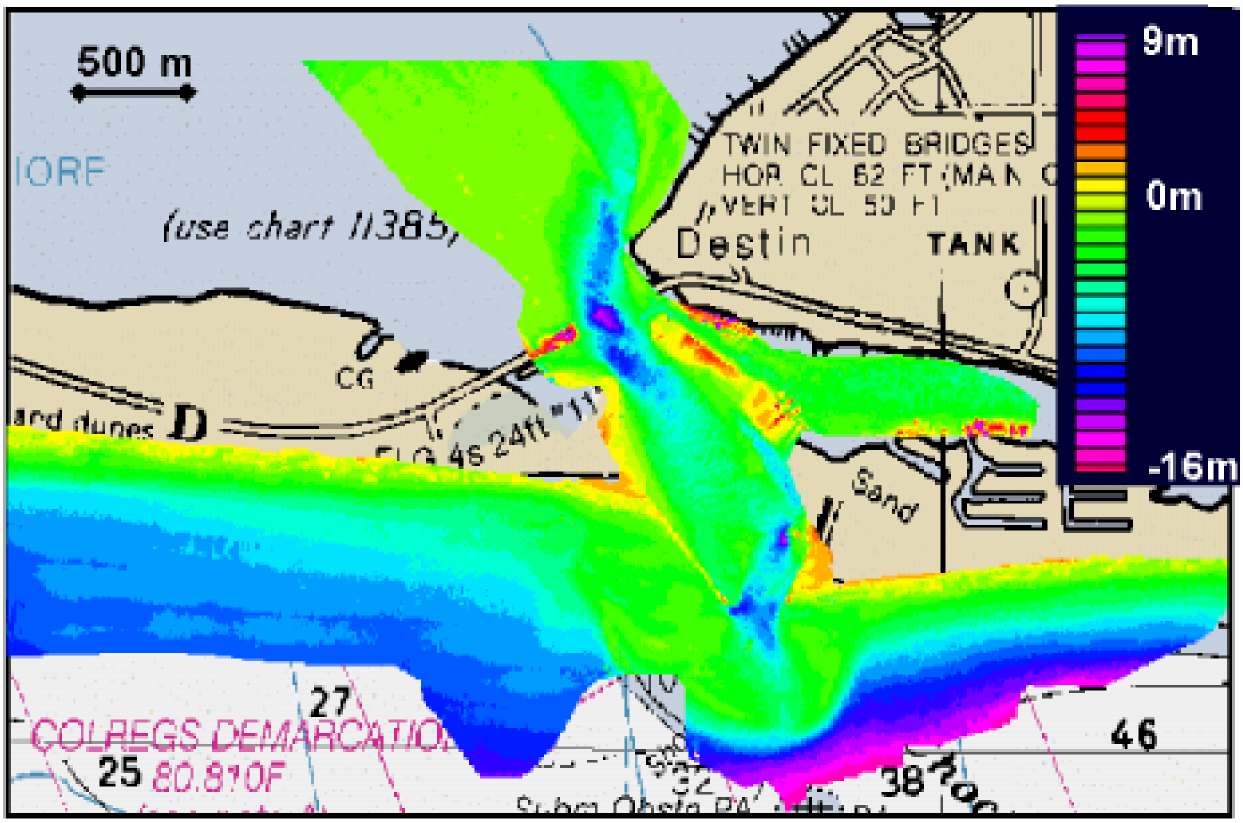

Figure 9. East Pass, Florida, U.S.A. NOAA nautical chart with contours of SHOALS data, December 1996.

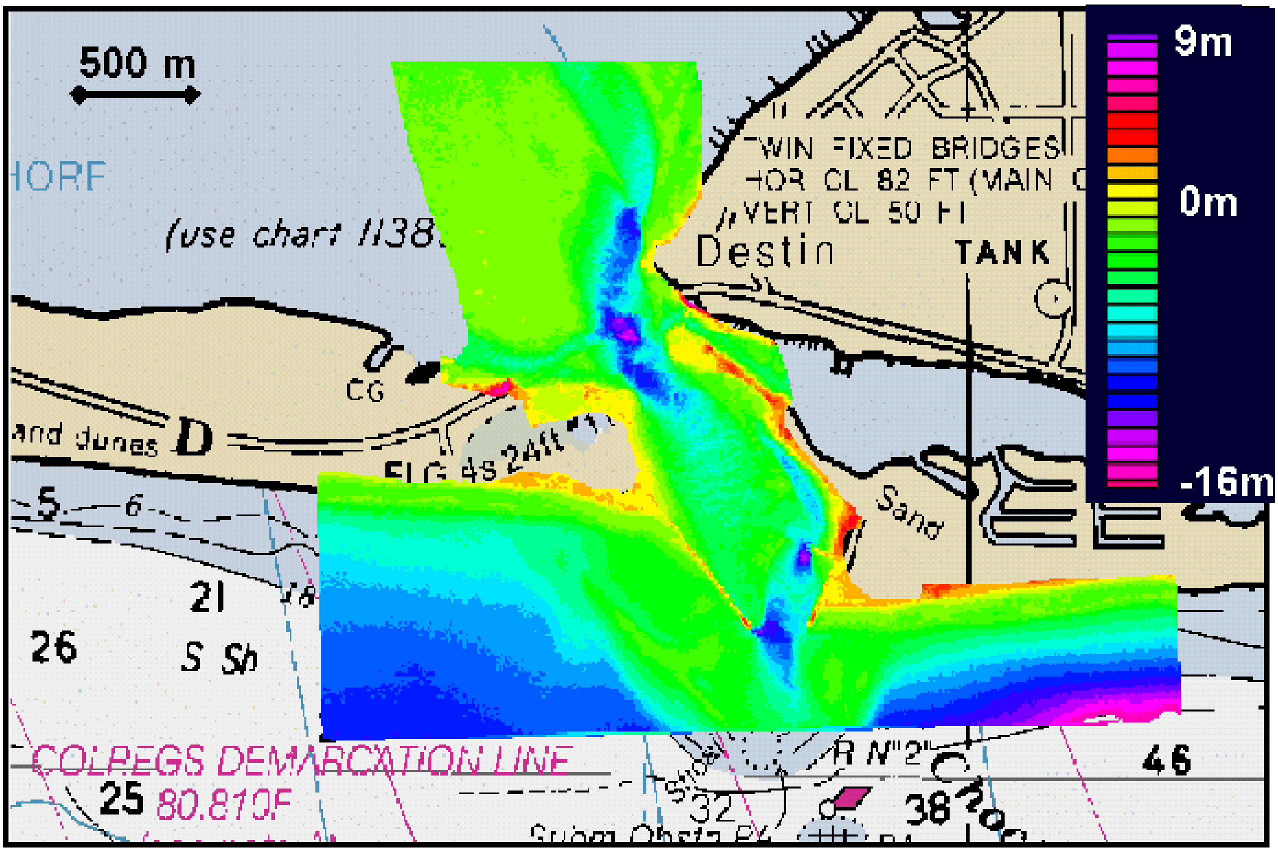

Figure 10. East Pass, Florida, U.S.A. NOAA nautical chart with contours of SHOALS data, November 1997.

to restore the deterioration caused by the high storm surges of Hurricane Opal. While the coverage of this survey is not as comprehensive as that of the 1996 survey, there is interesting information to be gained. The scour holes and navigation channel have continued to deepen and increase in spatial extent. This scouring is a recovery mechanism for the inlet system as it returns to an equilibrium state. The deep scour hole located between the jetty tips at the inlet mouth has shifted to a more north-south orientation. The deepest part of the navigation channel has moved eastward, continuing a historical trend of eastward migration for the inlet. The shoreline of Norriego Point has receded from the inlet interior, and is again in danger of breaching despite the artificial sand placement following the hurricane.

SHOALS SURVEY COMPARISONS AT EAST PASS, FLORIDA

Comparisons of SHOALS data sets show morphological changes that have occurred between surveys. The form of the comparison presented herein is an elevation-difference, or isopach, plot. For each depth location, an elevation difference between two surveys is computed. A negative difference indicates erosion, or that the elevation at a particular location is lower in the more recent survey. A positive elevation difference indicates accretion, or that the elevation at a particular location is higher in the more recent survey.

Isopach plots were created between all four SHOALS data sets collected at East Pass. A comparison between October and November 1995 is shown in the isopach contour overlay of Figure 11. A close-up of the central channel interior shows a red area of erosion where sand was dredged from the navigation channel. This close-up also shows alternating pink and blue areas (erosion and accretion, respectively) where sand waves in the navigation channel have migrated from one location to another. Figure 12 shows the comparison between the November 1995 and December 1996 surveys. The dark red areas between the jetty tips and at the northernmost extent of the comparison mark areas of scour. The bright blue-green area just inside the west jetty shows that there has been shoaling of the deep scour holes formed during the hurricane. Norriego Point is an accretive area of bright and dark blues area. The sand dredged from the channel was placed on the point to close the hurricane related breach. There is evidence of further migration of sand waves in the navigation channel (alternating areas of erosion and accretion). The area dredged in 1995 (see Figure 11)

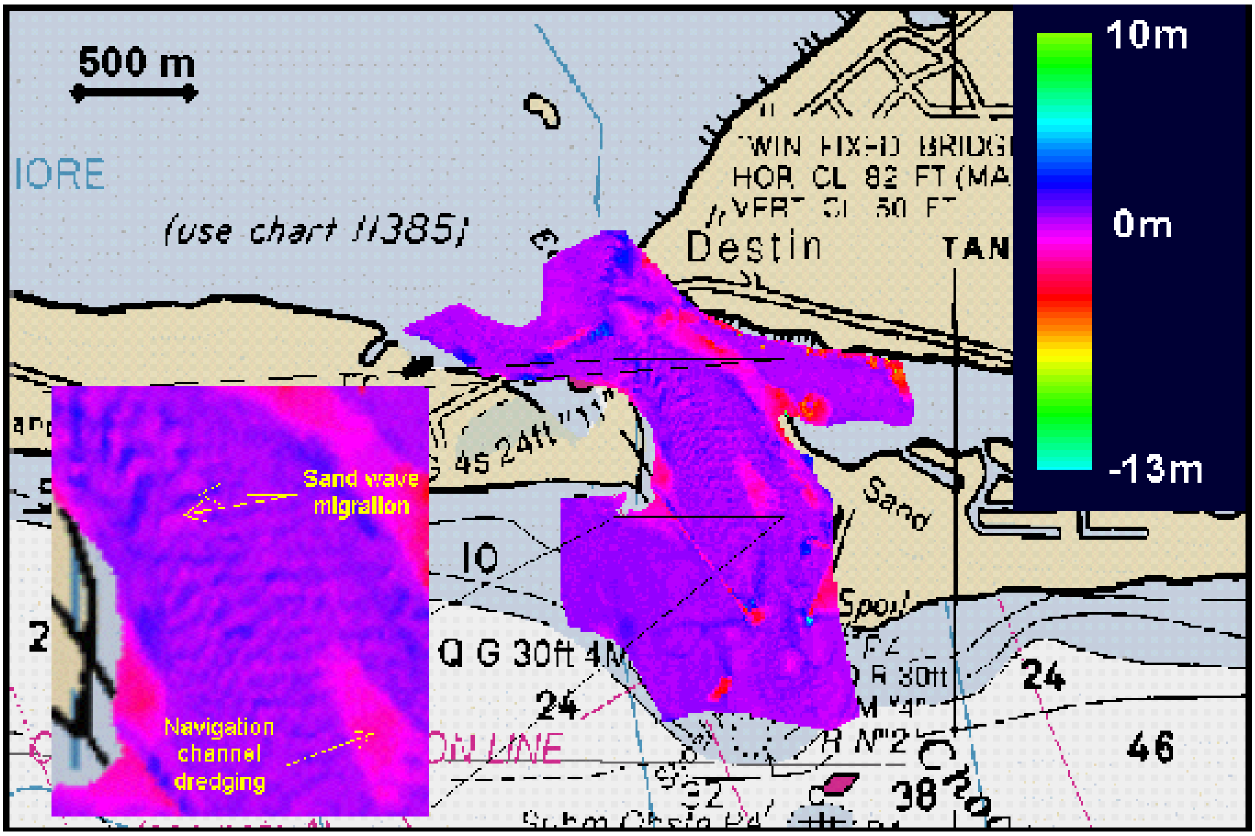

Figure 11. East Pass, Florida. Isopach contour plot, October to November 1995.

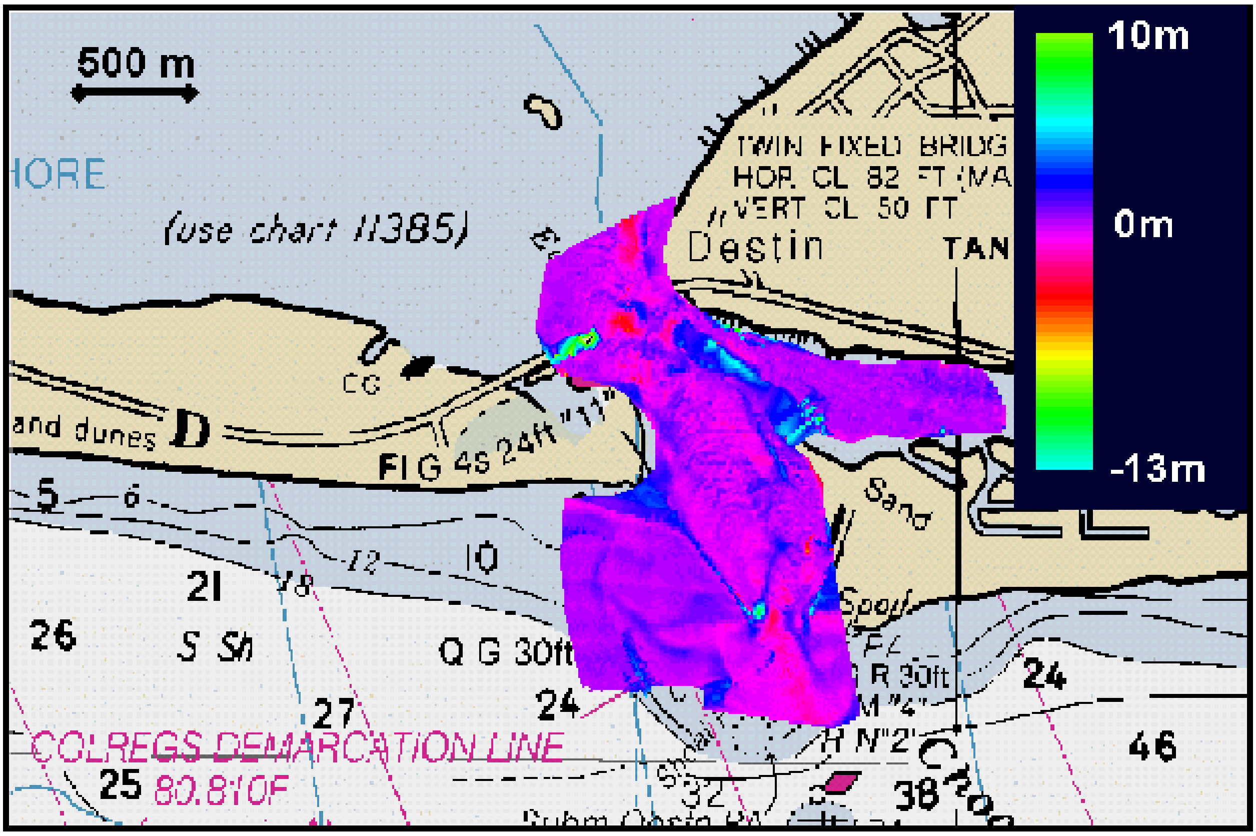

Figure 12. East Pass, Florida. Isopach contour plot, November 1995 to December 1996.

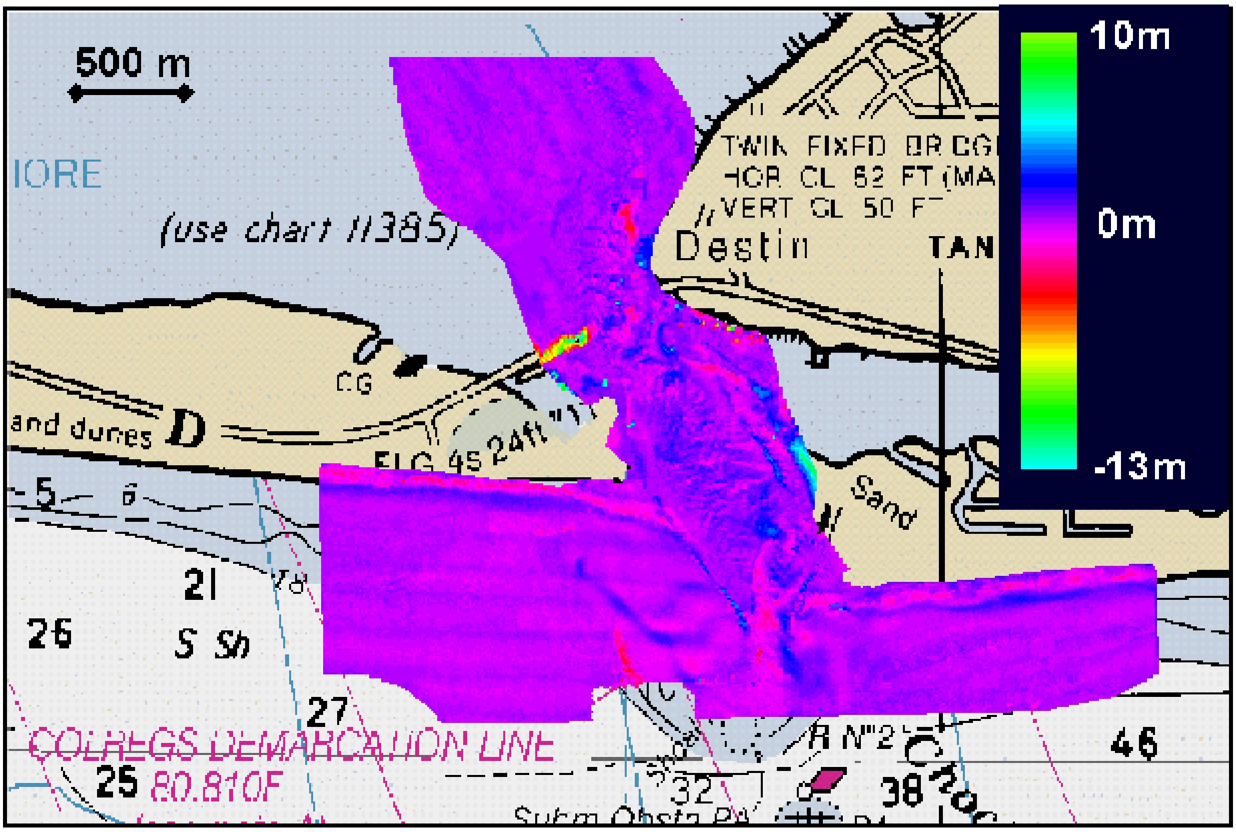

Figure 13. East Pass, Florida. Isopach contour plot, December 1996 to November 1997.

is now dark blue, indicating that this part of the navigation channel has shoaled. The arcing blue areas in the southwestern corner of the survey are swash bars that either newly formed or migrated to a new position on the ebb shoal. The comparison between the SHOALS data sets of December 1996 and November 1997 is shown in Figure 13. In this isopach contour plot, the realignment of the navigation channel to a more north-south orientation is visible as an area of red between the jetty tips. An area of red also indicates shoreline erosion on Norriego Point. Sand wave migration has once again occurred within the navigation channel. The shorelines of the adjacent beaches show first a line of erosion (bright pink) and then accretion (dark blue) directly south. This indicates seaward movement of alongshore sand bars. There are two dominant arcs on the southwestern portion of the ebb shoal. The red arc marks the former position of a swash bar (see Figure 12). The blue arc is the new location of a swash bar.

QUANTIFYING MORPHOLOGICAL CHANGES AT EAST PASS, FLORIDA USING SHOALS DATA

Computing volume changes of sand is one way to quantify morphological changes outlined in the previous paragraph. For the purposes of this paper, the entire inlet area was divided into major areas of interest: navigation channel, adjacent beaches, and ebb shoal. These areas are marked by a red line overlay on a NOAA nautical chart in Figure 14. The results of sand volume calculations for these areas are shown in Table 2. For those spaces in the table with an X, no data was available for one or both of the surveys for that particular area. A negative number indicates erosion, or a loss of material for an area, and a positive number indicates accretion for an area. The volumes in the table are given in thousands of cubic meters. The volumetric analysis at East Pass between 1995 and 1997 shows that the inlet system has lost material. This is likely a short-term effect directly related to the impacts of Hurricane Opal.

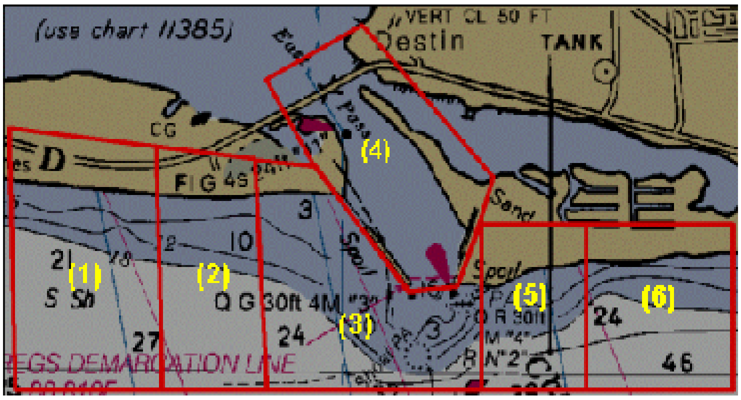

Figure 14. East Pass, Florida. Red lines delineate areas for sand volume calculations.

Table 2. Sand volume computations for East Pass, Florida. Volumes are thousands of m^3.

	1	2	3	4	5	6
1995	**X**	**X**	**1.6**	**5.3**	**X**	**X**
1995-1996	**X**	**X**	**-8.3**	**-10.8**	**X**	**X**
1996-1997	**-13.4**	**-5.2**	**-11.8**	**-1.2**	**-1.7**	**-8.0**

As part of the RSMDP, the volumes computed for the cells will be used in the creation of a sediment budget for the inlet. Future evaluation of sediment transport potential calculated for the cells defined in Figure 14 will be calibrated by the actual volumetric changes within these cells. These transport mechanisms include, but are not limited to waves, tidal and other currents, wind, and mechanical means such as dredging and beach nourishment.

CONCLUSIONS

Airborne lidar is an integral part of the RSMDP of USAED Mobile. Rapid collection of regional bathymetry and topography with SHOALS provides very high-density data sets over large regions. The data give a description of coastal terrain at a single instance in time. Coastal engineers can compare consecutive data sets to qualitatively and quantitatively evaluate morphological changes that have occurred between surveys. At East Pass, Florida, four SHOALS data sets show patterns of sand movement in the navigation channel, on the ebb shoal, and along the adjacent beaches. The development of large scour holes following Hurricane Opal was monitored using the surveys. A post-construction survey evaluated the repair of the rock jetty structures at the inlet. Volumes computed using SHOALS data sets will be incorporated into a sediment budget for the inlet. The same types of analysis presented in this paper for East Pass will be expanded to include the entire RSMDP.

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